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TECHNICAL REPORT BEES (W) 81-42

AN INDUSTRIAL HYGIENE EVALUATION OF AIRCRAFT REFUELING INSIDE CLOSED AIRCRAFT SHELTERS AT ELEVATED AMBIENT TEMPERATURES

JOSEPH A. MARTONE
BIOENVIRONMENTAL ENGINEERING SERVICES

OCTOBER 1981

FINAL REPORT
AUGUST 1981-SEPTEMBER 1981

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

USAF HOSPITAL WIESBADEN
APO NEW YORK 09220

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report BEES(W) 81-42	2. GOVT ACCESSION NO. AD-A114 396	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Industrial Hygiene Evaluation of Aircraft Refueling Inside Closed Aircraft Shelters at Elevated Ambient Temperatures		5. TYPE OF REPORT & PERIOD COVERED Final Report August 1981 - September 1981 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Joseph A. Martone, Major, USAF, BSC		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USAF Hospital Wiesbaden/SGP APO, New York 09220		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS USAF Hospital Wiesbaden/SGP APO, New York 09220		12. REPORT DATE October 1981 13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Availability of this report is specified on reverse of front cover

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft shelters	Fuel vapors	Aircraft
Jet fuel	Industrial hygiene	Aviation fuel
Refueling	Exposure	Charcoal tubes
		Monitoring

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

BEES(W) Technical Report 81-03, "An Industrial Hygiene Evaluation of Aircraft Refueling Inside Closed Aircraft Shelters" reported that personnel who participate in refueling aircraft with JP-4 in closed aircraft shelters could be exposed to high levels of fuel vapors when the ambient air temperature is greater than 25°C. This report presents results of three ~~additional~~ in-shelter aircraft refueling tests with ambient temperatures of 30°C or higher. For the specific situations studied, refuel crew personnel were exposed to total fuel vapor concentrations approaching permissible exposure limits. Exposure to

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benzene and other selected fuel vapor components were well below permissable exposure limits. The data were normalized ~~along with the results~~ reported in BEES(W) TR 81-03 to predict that personnel exposures above 50 percent of the short term exposure limit for fuel vapors would occur in both first and modified first generation shelters at elevated temperatures. The data support temperature limitations for in-shelter refueling with JP-4 in first and modified first generation shelters. No such limitations were found necessary for second or third generation shelters as they provide nearly three times the dilution volume of first generation shelters. To permit in-shelter refueling above the recommended temperature limits, restrictions on the amount of fuel transferred are suggested. Special consideration is given to the F-111 aircraft because of its large fuel capacity.

PREFACE

This industrial hygiene survey was conducted as part of a NATO evaluation of aircraft refueling in closed aircraft shelters. The study involved many NATO and USAF personnel in addition to our bioenvironmental team. Special gratitude is extended to Mr. Walter Will at HQ USAFE/DEMO for his role in coordinating the entire effort.

The individuals from the USAF Hospital Wiesbaden making significant contributions to the industrial hygiene survey and this report were:

Captain Nils Akerlind, Jr., Chemist
TSgt David J. Hawkins, Technician
Herr Dr. Klippel, Chemist
Mrs. Susie Jefferson, Secretary

This report has been reviewed by the public affairs officer and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

Headquarters USAFE/DEMO requested the USAF Hospital Wiesbaden to conduct industrial hygiene surveys as part of a NATO evaluation of aircraft refueling inside closed aircraft shelters. As a result, tests were conducted at three European locations to cover a wide range of environmental and physical conditions. The results of these industrial hygiene evaluations are given in USAF Hospital Wiesbaden Technical Report BEES(W) 81-03 (Reference 1).

Reference 1 recommends that refueling with JP-4 in a closed TABVEE (i.e. first generation)or 3rd generation aircraft shelter should be conducted only when the ambient air temperature (i.e. temperature in the shelter) is below 25°C to assure breathing zone fuel vapor concentrations below 50 percent of the permissible short term exposure limit (STEL). This recommendation was based on a plot of normalized JP-4 concentrations expressed as a percent of the STEL as a function of ambient temperature. It was necessary to normalize the average measured JP-4 concentrations to allow comparison of data from tests that involved different amounts of fuel transfer and shelter volume.

Reference 1 included relevant data from other studies which resulted in a total of nine data points being used to determine the 25°C limitation recommended for JP-4. Unfortunately only two data points were available for ambient temperatures above 25°C. For this reason both HQ USAFE/DEMO and the USAF Hospital Wiesbaden recommended additional testing with ambient temperatures above 25°C. This report describes and gives results of these additional tests. Description of the tests and discussion of test methodology and analytical methods is intentionally brief because these factors were essentially unchanged from the tests previously reported in Reference 1.

During the tests, representatives from Technischer Uberwachungs-Verein (TÜV) Rheinland made fuel vapor measurements near the aircraft fuel tank vents to define the explosive hazard region. These results are not included in this report but should be available from HQ USAFE/DEMO, APO NY 09012.

SECTION II

SHELTER DESCRIPTION AND TEST SCENARIOS

Three refueling tests using F-4 aircraft in a modified first generation aircraft shelter were made at Incirlik Common Defense Installation, Turkey on 1 September 1981. For test 1 the aircraft had been in the shelter overnight. The ambient air temperature just before refueling was 30°C; 7.6 m^3 of fuel was transferred. For test 2, the aircraft was brought into the shelter just after landing; the ambient temperature was 33.8°C and 8.8 m^3 of fuel was transferred. For test 3 the aircraft was brought into the shelter about two hours after landing. Between landing and test time the aircraft for test 3 was on an outdoor concrete surface in direct sunlight. For test 3 the ambient temperature was 34.7°C and 6.9 m^3 of fuel was transferred. For all tests JP-4 fuel was used with the refueler truck remaining outside of the shelter. The shelter main door and exhaust port door were completely closed, however a small access door remained open for the fuel line from the fuel truck. No mechanical ventilation was used during the tests. The shelter had a rectangular floor, approximately 30.8 m long and 14.6 m wide, and a 7.3 m radius semi-eliptical ceiling giving an interior volume of approximately 2600m^3. For each test the refueling time was about 8 minutes.

SECTION III

INDUSTRIAL HYGIENE CONSIDERATIONS

Since the fuel truck remained outside the shelter, the only pollutant released into the shelter was JP-4 fuel vapor displaced from the aircraft fuel tanks. Unfortunately there is no short term exposure limit (STEL) or workday permissible exposure limit (PEL) established specifically for jet fuel vapors. However, the limits developed for refined petroleum solvents are the most appropriate criteria for aviation fuels. The recommended standard (Reference 2) is 350 mg/m^3 for a 10 hour time weighted exposure (i.e. PEL) and 1800 mg/m^3 for a short term exposure (15 minutes) of personnel (i.e. STEL). These limits apply to total vapor concentrations of certain complex refined petroleum products; they are intended to take into account the toxicity of the many organic substances that make up these complex mixtures.

Considering the short time required for an in-shelter refueling, the health criteria which best applies is the STEL. The STEL (Reference 3) is the maximal concentration to which workers can be exposed for a period up to 15 minutes continuously without suffering irritation, irreversible tissue change or narcosis of sufficient degree to increase accident proneness or reduce work efficiency provided that no more than four exposures per day are permitted, with at least 60 minutes between exposure periods, and provided that the PEL is also not exceeded.

Benzene deserves special mention since it has toxic properties thought to be unique among hydrocarbon compounds. At high enough exposures over sufficient time periods, benzene exerts a toxic effect on the body's blood forming organs causing aplastic anemia and other severe disorders. Benzene is present in aviation fuels but most refiners find it more valuable as a petrochemical feedstock and so separate it from fuel streams for other uses. In the previous in-shelter refueling study (Reference 1) benzene exposure was not specifically considered because available data indicated the benzene content of JP-4 never to exceed 0.37 volume percent, therefore the benzene exposure limit would never be exceeded if the exposure limit for refined petroleum solvent was not exceeded. In this study benzene and other substances such as xylene, toluene, and ethylbenzene were considered to verify this assumption.

Table I lists the workday PEL's and STEL's for the individually measured substances (Reference 3). Reference 1 listed the PEL for benzene as 1 part per million (i.e. 3 mg/m^3) based on then current Air Force directives (ETAFOSH Standard 161-7, Reference 4). Since Reference 1 was published the Air Force announced (Reference 5) that ETAFOSH 161-7 was rewritten and now uses the limits shown in Table I.

TABLE I

WORKDAY PERMISSIBLE EXPOSURE LIMITS (PEL'S) AND SHORT TERM EXPOSURE LIMITS (STEL'S) FOR MEASURED JP-4 FUEL VAPOR COMPONENTS.

Measured Fuel Vapor Component	PEL * (mg/m^3)	STEL * (mg/m^3)
Benzene	30	75
Toluene	375	560
Xylene	435	655
Ethylbenzene	435	545

* (Reference 3)

SECTION IV

TEST PROCEDURES AND ANALYTICAL METHODS

Prior to each test, fuel crew members were outfitted with personal air sampling equipment designed to measure fuel vapor concentrations in their breathing zones. Only crew members who stayed inside the shelter during a test were outfitted. Two crew members were instrumented on each test. As soon as practicable after each test, the personal sampling gear was removed from the crew members. The sampling time was about 15 minutes.

In addition to crew member samples, three other samples for fuel vapors were obtained on each test. In some cases the sampling equipment was attached to bioenvironmental team members who walked about the shelter during a test, in other cases the sampling equipment was set up at a fixed location in the shelter. The samples obtained by both these methods are referred to as area samples.

The method for sampling fuel vapors involved sorption on large (8mm OD x 110mm) charcoal tubes. This is the procedure recommended by the National Institute for Occupational Safety and Health (NIOSH) for refined petroleum solvents (Reference 2). DuPont Model P-4000 personal sampling pumps were used to produce flow at a nominal rate of 0.6 liters per minute through the charcoal tube. A precision rotameter was used to measure the flow. The exact sample volume at normal temperature and pressure (i.e. 25°C and 760 mmHg) was calculated post test.

Charcoal tube analysis was performed at the USAF Hospital Wiesbaden. The technique requires fuel vapor desorption with carbon disulfide and detection by a gas chromatograph equipped with a non-polar column. Distilled JP-4 was used to determine the gas chromatograph calibration factor.

Fuel vapors were also sampled using organic vapor passive dosimeters. The passive dosimeters use charcoal as the sorbent material and rely on molecular diffusion to deposit organic vapors. The passive dosimeters were used to support an experimental passive dosimeter evaluation program conducted by the USAF Occupational and Environmental Health Laboratory, Brooks AFB, Texas and the USAF Hospital Wiesbaden and therefore this data is not presented in this report.

SECTION V

RESULTS AND DISCUSSION

Table II gives breathing zone concentrations of total fuel vapors and specific fuel vapor components measured during the three in-shelter aircraft refueling tests. Results are reported in milligrams fuel vapor per cubic meter of air and have been corrected to normal temperature and pressure to allow direct comparison with STEL's. Table II shows that total and component fuel vapor concentrations never exceeded the appropriate STEL's (see Table I).

The concentration of benzene in a bulk sample of JP-4 fuel taken just prior to testing was 1.8 volume percent. This benzene level is approximately five times greater than previously experienced in USAFE (Reference 1). Thus, it is particularly noteworthy that measured breathing zone benzene levels were still well below the benzene STEL and PEL.

Table III compares average measured breathing zone fuel vapor concentrations with values calculated from shelter volume and the volume of fuel transferred with the assumption of a well mixed shelter. An example of this calculation is given in Appendix A of Reference 1. The average deviation between measured and calculated concentrations is 37 percent, this compares to an average deviation of 69 percent for data taken with ambient temperatures between -5.0 and 16.6°C (Reference 1). The better agreement obtained in this study supports the argument of better in-shelter mixing at elevated ambient temperatures.

The elevated temperature fuel vapor concentration data presented in this report must be considered better quality than the high temperature data taken at Larissa, Greece and reported in Reference 1. At Larissa, the high fuel vapor concentrations resulted in some break through of fuel vapors on the charcoal sampling tubes and this necessitated a theoretical calculation of vapor concentration to take into account fuel vapor penetration (Reference 1). This calculation is conservative in that it tends to overpredict actual concentrations (Reference 6). For tests at Incirlik, vapor penetration was avoided by using large charcoal tubes (i.e. packed with 600 mg charcoal) rather than the small charcoal tubes (i.e. packed with 150 mg charcoal) used at Larissa.

TABLE II

BREATHING ZONE TOTAL FUEL VAPOR AND FUEL VAPOR COMPONENT CONCENTRATIONS MEASURED DURING IN-SHELTER AIRCRAFT REFUELING.

Sample Location	Test No.	CONCENTRATION (mg/m^3) Total Fuel Vapor	Benzene	Toluene	Xylene	Ethylbenzene
Crew Chief	1	870	7.6	8.0	3.5	1.3
Refueler Technician	1	1300	12	13	5.4	2.1
Area	1	1500	15	15	6.1	2.3
Area	1	1400	13	13	5.1	2.1
Area	1	630	5.6	5.4	2.4	0.8
Average	1	1100	11	11	4.5	1.7
Crew Chief	2	1000	11	---	---	---
Refueler Technician	2	1800	18	22	11	4.2
Area	2	1300	13	15	7.0	2.8
Area	2	460	5.0	5.2	2.8	1.2
Area	2	610	< 0.8	---	---	---
Average	2	1000	10	14	6.9	2.7
Crew Chief	3	1100	11	14	6.7	2.6
Refueler Technician	3	1100	13	6.3	1.1	0
Area	3	1000	11	12	3.6	2.5
Area	3	820	8.9	11	5.3	2.0
Area	3	520	5.6	6.9	3.5	1.4
Average	3	900	10	10	4.0	1.7

--- = Not Analyzed

TABLE III

COMPARISON OF MEASURED AND CALCULATED FUEL VAPOR CONCENTRATIONS

Test	Average Measured Concentration (mg/m^3)	Calculated Concentration (mg/m^3)	Percent Difference $\frac{\text{Calc - Measured}}{\text{Calc}} \times 100$
1	1100	1500	27
2	1000	1800	44
3	900	1500	40

The data presented in this report show that for the conditions evaluated, in-shelter breathing zone fuel vapor concentrations do not exceed the STEL. However, we have not studied a possible worst case condition. For example, suppose 13 m^3 of JP-4 was transferred to an F-4 in a smaller shelter (i.e. first generation shelter volume is about 1850 m^3) with ambient temperatures greater than 30°C. Would the STEL be exceeded? To answer this question we need to consider all the JP-4 in-shelter fuel vapor data from this report and from Reference 1. The JP-4 data is not directly comparable because each test involved a different combination of primary variables such as the amount of fuel transferred, shelter volume, and ambient temperature. Secondary variables such as the aircraft type, location of fuel tank vents, condition of the aircraft prior to test, fuel temperature, or the rate of fuel transfer are considered to be of relatively minor importance in predicting average breathing zone fuel vapor concentrations during in-shelter refueling. Although the minor contribution of these assumed secondary factors has not been proven, this is a necessary simplification for a first attempt to correlate a limited amount of field data. For example, we are assuming that the ambient air temperature in the shelter correlates in some way with the JP-4 equilibrium vapor pressure in the fuel tank and therefore relates to the percentage of fuel vapor contained in the fuel vapor/air mixture that is vented into the shelter. In fact, the liquid fuel in the fuel tank is probably not in thermal equilibrium with the ambient air or the fuel vapor/air mixture above the liquid level. However, it is not practical to take all these variables into account and as we shall see, ambient temperature, seems to correlate the data reasonably well.

Reference 1 normalized the measured JP-4 fuel vapor concentrations by dividing the averaged raw data by the shelter volume and the amount of fuel transferred. The normalized concentrations were expressed as a percentage of a normalized STEL and plotted versus temperature. In this report a slightly different normalization procedure is used. This new procedure is perhaps less abstract and better distinguishes between shelters types.

The new procedure assumes that average measured breathing zone fuel vapor concentrations are directly proportional to the amount of fuel transferred and inversely proportional to the shelter volume. In other words as the fuel transferred increases so does the amount of fuel vapor discharged from the fuel tank vents and this results in higher breathing zone fuel vapor concentrations. Also, as the shelter volume increases the fuel vapor concentration should decrease owing to the larger dilution volume. The latter argument assumes good shelter mixing; this assumption improves as the ambient temperature increases (see discussion for Table III).

Using the approach outlined above, all of the averaged JP-4 concentrations were normalized for the interior volume of a first (I), modified first (Mod I), and third generation (III) shelter according to equation 1;

$$\underset{(\text{mg/m}^3)}{\text{Normalized Concentration}} = \underset{(\text{mg/m}^3)}{\text{Average Measured Concentration}} \times \frac{\text{Actual shelter Volume } (\text{m}^3)}{\text{Interior Volume of I, Mod I or III Generation Shelter } (\text{m}^3)} \times \frac{13 \text{ m}^3}{\text{Actual Amount of Fuel Transferred } (\text{m}^3)} \qquad (1)$$

Equation 1 normalizes the data to an assumed worse case of 13 m^3 of fuel transferred. Table IV gives the approximate maximum amount of fuel that would be transferred for the aircraft subject to in-shelter refueling in USAFE (Reference 7). The figures in Table IV assume that aircraft will always have at least 10 percent of their maximum fuel capacity as a reserve prior to in-shelter refueling. Table IV shows that, except for the F-111, the assumed worst case of 13m^3 for fuel transfer is good for all aircraft. The F-111 is considered separately later on in this discussion.

TABLE IV

EXPECTED MAXIMUM FUEL TRANSFER AMOUNTS FOR USAFE AIRCRAFT SUBJECT TO IN-SHELTER REFUELING.

Aircraft Type	Maximum Amount of Fuel Transfer* (m^3)
F-4	11
F-15	13
A-10	12
F-111	25
F-16	<13

* Assumes 10 percent fuel reserve prior to refueling.

Table V shows the normalized data for tests 1-3 reported in this study and for JP-4 tests (i.e. tests A, B, F, G, H, I, J, K, L) reported previously (Reference 1). Table V also shows the data averaged for tests conducted at nearly the same ambient temperature. For example, the results for tests I, J, K, and L were averaged because all of these tests were performed at about 16°C. Here is an example of how Table V may be interpreted. For test 1 the average measured breathing zone fuel vapor concentration was 1100 mg/m^3. Test 1 involved a modified first generation shelter and 7.6 m^3 of fuel was transferred. Table V predicts that if 13m^3 of fuel was transferred on test 1 then the averaged breathing zone fuel vapor concentration would have been 1900 mg/m^3. Table V also predicts that if test 1 had been in a first generation shelter or a third generation shelter and 13 m^3 of fuel were transferred the resulting average fuel vapor concentration would have been 2700 mg/m^3 and 960 mg/m^3 respectively. Note that the predicted concentrations for the first and modified first generation shelter are over the STEL.

The natural logarithm of the average normalized fuel vapor concentrations for each shelter type are plotted as a function of temperature in Figure 1. The lines drawn on Figure 1 are best fit lines determined by a least squares analysis of the data. The correlation coefficient is 0.85 which means that we are 93 percent confident that a correlation exists between the plotted variables. A straight line fit of the data was assumed appropriate because JP-4 equilibrium vapor pressure data would give a straight line if plotted in the same fashion and because our simplified model for theoretically predicting in-shelter fuel vapor concentrations (see Appendix A of Reference 1) assumes a direct relationship between fuel vapor concentration and JP-4 vapor pressure for a given shelter volume and amount of fuel transfer. If we select 50% of STEL (900 mg/m^3) as the level not to be exceeded inside of a shelter then

Figure 1 shows that the maximum fuel transfer of $13m^3$ should not be made in first generation shelters when the ambient temperature exceeds 18°C and should not be made in modified first generation shelters above 25°C. Figure 1 also shows that this recommended restriction is not needed for third generation shelters or second generation shelters (i.e. second generation shelters are larger than third generation shelters). Reference 1 did not make this distinguishment. The arbitrarily selected criteria of 50 percent of the STEL is not considered overly conservative in view of the assumptions and averaging techniques used in data analysis and because small increases in ambient temperature near 25°C result in large increases in average in-shelter fuel vapor concentration.

Figure 1 assumed a worst case fuel transfer of $13m^3$ and this resulted in the recommended temperature restrictions outlined above. However, we can use equation 1 to predict maximum recommended fuel transfer amounts that would keep average breathing zone fuel vapor concentrations below 900 mg/m^3 for situations when the ambient temperature exceeded the recommended worst case analysis limits. Table VI shows the results of these calculations for the various shelter types. For example, Table VI says that if the ambient temperature were 30°C we would recommend limiting the amount of fuel transfer in a first generation shelter to 6.8 m^3 and to 9.9 m^3 in a modified first generation shelter.

The F-111 aircraft needs to be considered separately because of its large fuel capacity. The F-111 is sheltered only in second or third generation shelters in the United Kingdom. Since second generation shelters are slightly larger than third generation shelters equation 1 was used to normalize the data assuming a worst case of 5100 m^3 shelter volume (i.e. third generation shelter) and 25 m^3 of fuel transfer. The result is that no restriction on fuel transfer is needed for F-111 aircraft when ambient temperatures are below 25°C. For temperatures above 25°C, the reduced fuel transfer amounts shown in Table VI are recommended.

If the recommended temperature and fuel transfer amount restrictions for closed aircraft shelters are implemented in USAFE it is not believed that this will seriously impact the peacetime practice of in-shelter refueling. Table VII shows mean high and low temperatures for the warmest months at the coldest and warmest recording stations in selected countries (Reference 8). With the proposed restrictions, limits on the amount of fuel transferred may be needed in southern USAFE during warm months. This is not expected to be of any practical consequence since the average amount of fuel transferred considering all tests was only 8 m^3. If this average is typical of everyday operations then Table VI indicates that fuel transfer could take place in a first generation shelter with ambient temperatures as high as 27°C.

TABLE V
NORMALIZED JP-4 FUEL VAPOR DATA

TEST NO.	AVERAGE MEASURED CONCENTRATION (mg/m^3)	ACTUAL SHELTER VOLUME (m^3)	ACTUAL FUEL TRANSFERRED (m^3)	AMBIENT TEMPERATURE (°C)	NORMALIZED CONCENTRATION ACCORDING TO SHELTER TYPE * (mg/m^3) I	Mod I	III	(AVERAGED RESULTS) AMBIENT TEMPERATURE (°C)	NORMALIZIED CONCENTRATION ACCORDING TO SHELTER TYPE (mg/m^3) I	Mod I	III
1	1100	2600	7.6	30.0	2700	1900	960				
2	1000	2600	8.8	33.8	2100	1500	760	32.8	2400	1700	860
3	900	2600	6.9	34.7	2400	1700	870				
A	900	1850	8.8	26.7	1300	950	480				
B	1700	1850	7.8	26.7	2800	2000	1000	26.7	2100	1500	740
F	190	1500	4.0	-5.0	500	360	180				
G	130	1500	4.0	-5.0	340	240	120	-5	420	300	150
H	280	1850	11.3	12.8	320	230	120	12.8	320	230	120
I	140	5100	5.3	16.6	940	670	340				
J	30	1850	1.8	16.6	210	150	76	16.3	690	490	250
K	410	5100	11.2	16.1	1300	930	470				
L	110	5100	13.4	16.1	300	210	110				

* NORMALIZED USING EQUATION 1

TABLE VI

MAXIMUM RECOMMENDED JP-4 FUEL TRANSFER VOLUMES FOR CLOSED AIRCRAFT SHELTERS.

AMBIENT TEMP. (°C)	MAXIMUM RECOMMENDED FUEL TRANSFER (m^3)		
	First Generation Shelter	Modified First Generation Shelter	Third or Second Generation Shelter with F-111
<18	13	13	25
18	13	13	25
19	12.3	13	25
20	11.7	13	25
21	11.0	13	25
22	10.6	13	25
23	9.9	13	25
24	9.5	13	25
25	9.0	13	25
26	8.6	12.3	23.5
27	8.0	11.7	22.5
28	7.7	11.0	21.1
29	7.3	10.6	20.3
30	6.8	9.9	19.1
31	6.5	9.5	18.2
32	6.2	9.0	17.3
33	5.9	8.6	16.5
34	5.6	8.0	15.3
35	5.3	7.7	14.8

TABLE VII

HIGH AND LOW MEAN TEMPERATURES
FOR SELECTED COUNTRIES

GERMANY

Grafenwoehr/Coldest

	High Mean	Low Mean
May	17.2	6.0
Jun	21.1	9.4
Jul	22.7	10.5
Aug	21.1	10.0
Sep	18.3	7.2
Oct	13.8	3.3

Heidelberg/Warmest

	High Mean	Low Mean
May	19.4	9.4
Jun	22.7	12.7
Jul	25.0	13.8
Aug	23.8	13.8
Sep	21.1	11.1
Oct	15.0	4.4

ENGLAND

Prestwick/Coldest

	High Mean	Low Mean
May	15.5	6.6
Jun	17.2	9.4
Jul	18.8	11.6
Aug	18.8	11.1
Sep	16.1	9.4
Oct	12.7	6.6

London/Warmest

	High Mean	Low Mean
May	17.7/15.5	7.7
Jun	21.1	11.1
Jul	22.2	12.7
Aug	21.6	12.2
Sep	19.4	10.5
Oct	15.0	7.2

TURKEY

Ankara/Coldest

	High Mean	Low Mean
May	18.8	9.4
Jun	26.6	12.2
Jul	30.0	15.0
Aug	30.5	15.5
Sep	25.5	11.1
Oct	20.5	6.6

Incirlik/Warmest

	High Mean	Low Mean
May	27.2	14.4
Jun	31.6	18.8
Jul	33.8	21.6
Aug	35.5	22.2
Sep	32.7	18.8
Oct	28.3	12.7

ITALY

Aviano/Coldest

	High Mean	Low Mean
May	21.1	11.6
Jun	24.4	15.0
Jul	27.2	17.2
Aug	26.6	16.6
Sep	23.3	13.8
Oct	18.3	8.3

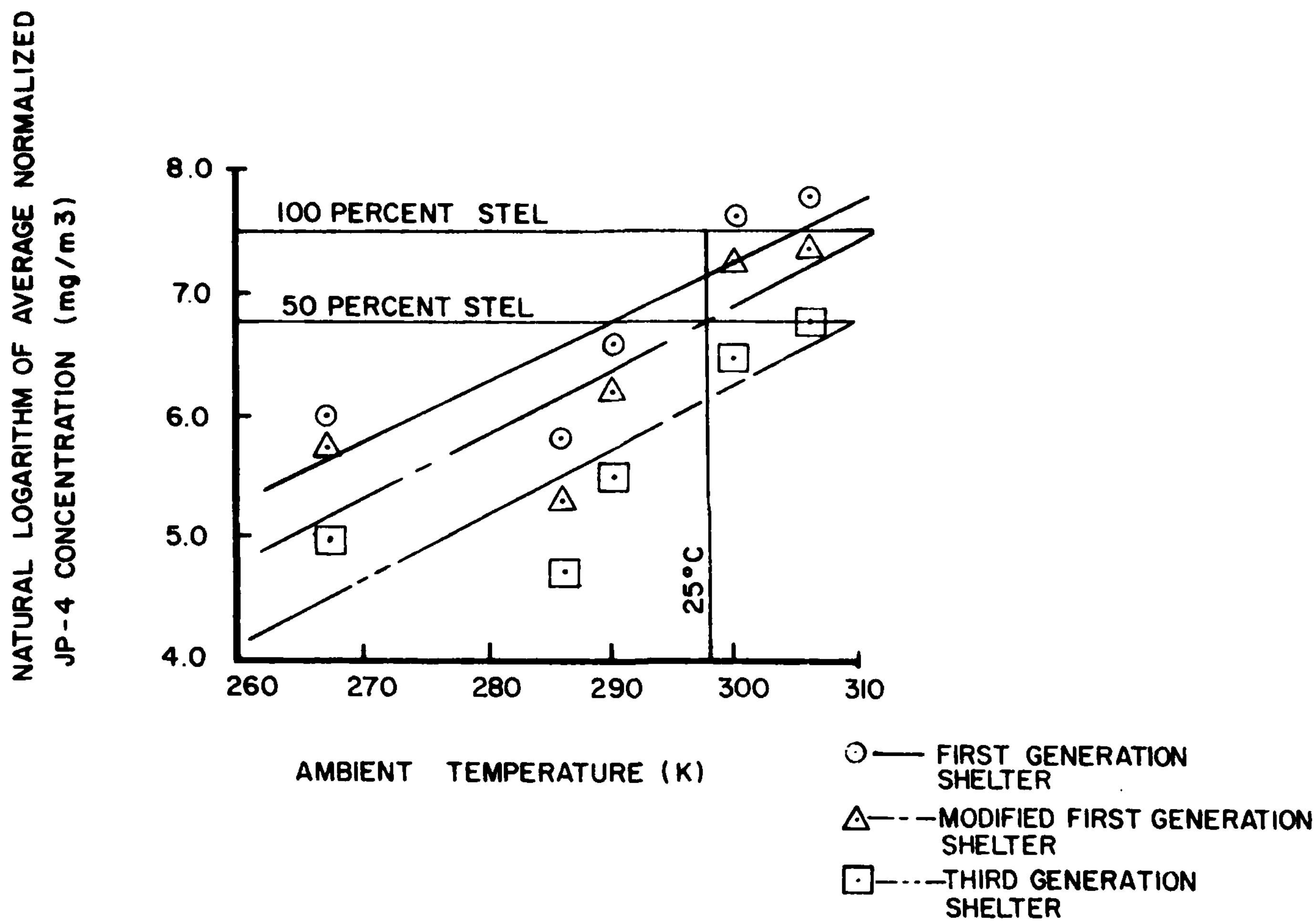
Sicily/Warmest

	High Mean	Low Mean
May	25.5	11.6
Jun	29.4	15.0
Jul	32.7	17.7
Aug	33.3	18.8
Sep	30.0	16.6
Oct	25.0	13.3

NOTE: All temperatures in °C

FIGURE 1

AVERAGE NORMALIZED JP-4 CONCENTRATIONS AS A FUNCTION OF AMBIENT TEMPERATURE FOR VARIOUS SHELTER TYPES



The definition of an STEL stipulates that no more than four short (i.e. < 15 minutes) excursions up to the maximal limit occur in a duty day with at least 60 minutes between exposure periods (see STEL definition in Section III). This is interpreted to mean that an individual should not be inside a closed shelter during an aircraft refueling more than four times a duty day and should have at least 60 minutes of low exposure (i.e. below the PEL) between refuelings. To minimize problems in applying this guideline, it should be used for all JP-4 transfers in closed aircraft shelters regardless of shelter type, ambient temperature, or amount of fuel transfer. Although this is a conservative interpretation, it hopefully can be observed without serious operational impact on peacetime practice of aircraft refueling in closed aircraft shelters. The suggested guideline does not limit the number of in-shelter refuelings in a day; it does, however, mean that refueling crews may have to be rotated to limit an individual's exposure.

The STEL definition also states that the daily time weighted average exposure limit (i.e. PEL) must not be exceeded. An assumed exposure at the STEL (1800 mg/m^3) for 15 minutes four times in a day with no exposure during the remaining duty day results in a time weighted average exposure of 225 mg/m^3; well below the PEL. Therefore, it is very unlikely that a crew member's average daily exposure would exceed the PEL even if he or she participated in the suggested maximum of four in-shelter refuelings during the duty day. Nevertheless, supervisors should be aware of this possibility and should avoid assigning and individual to other tasks which would involve exposure to high levels of fuel vapors on the same duty day that the individual participated on several in-shelter refuelings.

If the recommended limitations for in-shelter refueling prove to be too restrictive there are some possible alternatives. One alternative is to install duct work to route the displaced fuel vapors outside the shelter. Another possibility is to outfit fuel crew members with organic vapor respirators. These alternatives have some disadvantages. Thus, trade-offs would have to be considered in detail at a later date if the recommended limitations prove unsatisfactory.

The above discussion applies to in-shelter refueling with JP-4. Reference 1 concluded that no restrictions are needed when refueling with JP-8 because of its low vapor pressure compared with JP-4. Therefore, the limitations recommended in this report are academic for the United Kingdom where JP-8 is typically used rather than JP-4.

SECTION VI

RECOMMENDATIONS

Based on information presented in this report we recommend the following limitations on peacetime JP-4 refueling in closed aircraft shelters:

1. No ambient temperature or fuel transfer volume restrictions are needed for second or third generation aircraft shelters, except for F-111 aircraft when ambient air temperatures are above 25°C. For temperatures above 25°C fuel transfer volumes for F-111 aircraft should be limited as shown in Table VI.

2. For modified first generation shelters, no limitation on fuel transfer volume is needed at ambient temperatures below 25°C. Above 25°C, Table VI gives maximum recommended fuel transfer volumes.

3. For first generation shelters, no limittation on fuel transfer volume is needed at ambient temperatures below 18°C. Above 18°C, Table VI gives maximum recommended fuel transfer volumes.

4. Fuel crew members who participate in in-shelter refueling should be limited to a maximum of four in-shelter refuelings per duty day and should have at least a 60 minute period of low (i.e. below the PEL) or no fuel vapor exposure between refueling aircraft in a shelter.

These findings do not eliminate the need for continued workplace industrial hygiene good practice and periodic monitoring at the local level. This report should serve as useful guidance for USAFE medical facility personnel when planning and performing industrial hygiene surveys of in-shelter refueling.

REFERENCES

1. Martone, J.A., "An Industrial Hygiene Evaluation of Aircraft Refueling Inside Closed Aircraft Shelters," TR BEES (W) 81-03, January 1981.

2. "Criteria for a Recommended Standard: Occupational Exposure to Refined Petroleum Solvents," NIOSH TR 77-192, 1977.

3. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981," American Conference of Governmental Industrial Hygienists, 1981.

4. "Exposure to Benzene," ETAFOSH Standard 161-7, undated.

5. AFMSC/SGPA letter "BEE Update", 28 Aug 1981.

6. Peterson, J.E., "Calculation of Vapor Penetration in Charcoal Sampling Tubes", AIHA Journal, June 1980.

7. Personal Communication, HQ USAFE/DEMO, Ramstein AB, Germany, October, 1981.

8. Personal Communication, 31st Weather Squadron, Rhein Main AB, Germany, December 1980.

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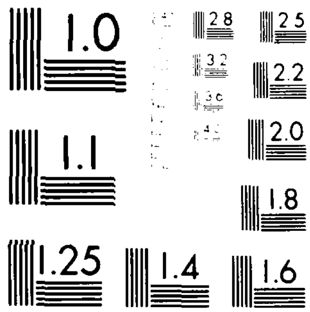

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INFORMATION

DEPARTMENT OF THE AIR FORCE
UNITED STATES AIR FORCE REGIONAL MEDICAL CENTER WIESBADEN (USAFE)
APO NEW YORK 09220

REPLY TO ATTN OF: SGB

SUBJECT: Addendum to Technical Report BEES(W) 81-42

TO: DTIC/DDA

JUN 27 [illegible]3

Our records show that we sent you Technical Report BEES(W) 81-42. Please affix the enclosed addendum to your copy.

Joseph A. Martone

JOSEPH A. MARTONE, Maj, USAF, BSC
OIC, Industrial Hygiene Engineering

Addendum to Technical Report BEES(W) 81-42
"An Industrial Hygiene Evaluation of Aircraft
Refueling Inside Closed Aircraft Shelters at
Elevated Ambient Temperatures"

AFOSH Standard 161-8[1] requires use of the most recent ACGIH[2] Threshold Limit Value(TLV) publication for evaluating occupational exposures to chemical substances in Air Force workplaces. The ACGIH updates their TLV publication annually. When TR BEES(W) 81-42 was written the short term exposure limit(STEL) definition found in the 1981 ACGIH TLV publication (Reference 1) was used to interpret workplace fuel vapor exposures. The current (i.e. 1982) ACGIH TLV publication (Reference 2) has an STEL definition significantly different from the 1981 version. Thus it is necessary to re-evaluate the recommendations of BEES(W) 81-42 considering the current STEL definition.

Recommendation number 4 (see pg 17) of BEES(W) 81-42 requires reconsideration because of the STEL definition change. The recommended maximum of four in-shelter refuelings per day per individual was based on the 1981 STEL definition which limited short term exposures to four "excursions" a day with at least 60 minutes between exposures. The problem with the 1981 STEL definition is that the term "excursion" was not defined. Each in-shelter refueling was considered an excursion period hence the recommended limit of four per day per individual.

The 1982 STEL definition eliminates the term "excursion" and instead says that short term exposures "at the STEL should not be repeated more than four times per day." Recommendations 1-3 of BEES(W) 81-42 effectively preclude "exposures at the STEL" during in-shelter refuelings since these recommendations were developed assuming that it was always desirable to keep in-shelter refueling exposures below 50 percent of the STEL. Therefore the four times a day limit contained in the current STEL definition does not have a bearing on in-shelter refueling assuming that recommendations 1-3 are observed.

The STEL definition also requires that the daily time weighted average PEL is not exceeded. To determine whether or not this condition is met would require full workday measurements of an individual's fuel vapor exposure on a day when he or she participated in many in-shelter refuelings. This would be a worst case test. All EHL measurements to date were during a single in-shelter refueling rather than a person's entire workday. With a few assumptions it is possible to estimate the number of in-shelter refuelings a person could perform in a day without exceeding the daily PEL for fuel vapors.

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1 AFOSH standard 161-8 does not apply if a substance specific AFOSH standard has been published (e.g. asbestos, benzene, hydrazine etc.)

2 American Conference of Governmental Industrial Hygienists

The PEL for jet fuel is 350 mg/m^3 for a 10 hour time weighted exposure (see TR BEES(W) 81-42 for discussion of this PEL). Thus the permissible daily exposure is:

$$350\ \frac{mg}{m^3} \times 10\ hr \times 60\ \frac{min}{hr} = 210{,}000\ \frac{mg\text{-}min}{m^3}$$

During an in-shelter refueling assume that an individual experiences a fuel vapor concentration of 900 $\frac{mg}{m^3}$ (i.e. 50 percent of the STEL) for 30 minutes (This is a worst case assumption if recommendations 1-3 of TR BEES (W) 81-42 are observed). The exposure would be:

$$900\ \frac{mg}{m^3} \times 30\ min = 27{,}000\ \frac{mg\text{-}min}{m^3}$$

To keep within the PEL an individual should not perform more than:

$$\frac{210{,}000}{27{,}000} = 8 \text{ in-shelter refuelings in a day.}$$

Because the limit of 8 refuelings is a conservative estimate and because an individual would only rarely exceed this number, there should be no regulatory limit on the number of refuelings a person could perform in one day. If future field measurements of a refueler's whole day fuel vapor exposure contradict this recommendation then limits on the number of refuelings per day or a limit on a person's daily total time in-shelter during refueling should be reconsidered.

This analysis considers fuel vapor exposure during in-shelter aircraft refueling. When refueling is accomplished with a pantograph or with the fuel truck located outside the shelter fuel truck exhaust is not emitted in the shelter and therefore fuel vapors are rightfully the only concern. When refueling occurs with fuel truck exhaust emitted inside the shelter or when other AGE equipment is used during the time the shelter is closed then the combustion generated pollutants from these sources must be considered in judging the workplace environment. An upcoming EHL technical report on an F-16 in-shelter refueling study at Hahn AB will discuss combustion generated pollutants in more detail.

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References

1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981", American Conference of Governmental Industrial Hygienists, 1981.

2. "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1982", American Conference of Governmental Industrial Hygienists, 1982.

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